1-1-1974

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Introduction

The post-tectonic Tunk Lake granite pluton (Fig. 1) is exposed over a circular area of 180 km^2 in southeastern Maine. It intrudes the Ordovician (?) Ellsworth Schist, the middle Paleozoic Bays-of-Maine gabbroic-granitic complex, and Middle Devonian biotite granite and quartz monzonite (Karner, 1968). A preliminary K-Ar date (Karner, in preparation) is late Middle Devonian (357 ± 10 MY).

The purpose of this paper is to summarize briefly the geology of the pluton following closely the work reported in Karner (1968), and Karner and Helgesen (1970) and also to discuss the pluton's possible relationships to the Maine Coastal plutons, the White Mountain plutonic-volcanic series, the tectonic history of the northern Appalachians, and to possible New England melting-anomaly activity as discussed in the above references, Karner and Bertram (1972) and Karner (1973, and in preparation).

Rock Types

The outermost rocks of the pluton are magnetite-aegirine augite granites containing sodium-rich microperthite. These grade inward to hornblende and biotite granites and biotite quartz monzonite. Six rock types, distributed in concentric zones, can be distinguished by texture, quartz and feldspar contents, and common ferromagnesian minerals (Table 1). Their outcrop areas are shown on Figure 1 except for type I which occurs at the margin of the pluton. In adjacent zones, rock types are gradational so that contacts between zones are arbitrary and have been placed according to characteristics given in Table 1.

Type I: Magnetite-Aegirine Augite Granite

Type I occurs in the contact zone of the pluton. Table 1 describes its texture and major mineral content. Magnetite and aegirine augite occur as subhedral to euhedral grains 1 to 2 mm long. Microperthite occurs as subhedral tabular grains from 1/2 to 3/4 cm long. Some phases of the granite contain up to about 15 percent oligoclase as discrete grains from 1/4 to 1/2 cm long. Quartz occurs as anhedral grains from 1/4 to 1/2 cm in diameter. Euhedral zircon, sphene, apatite, and allanite-epidote are common accessories. Fayalite is present in some specimens. The contact zone, about 30 meters wide at the east margin

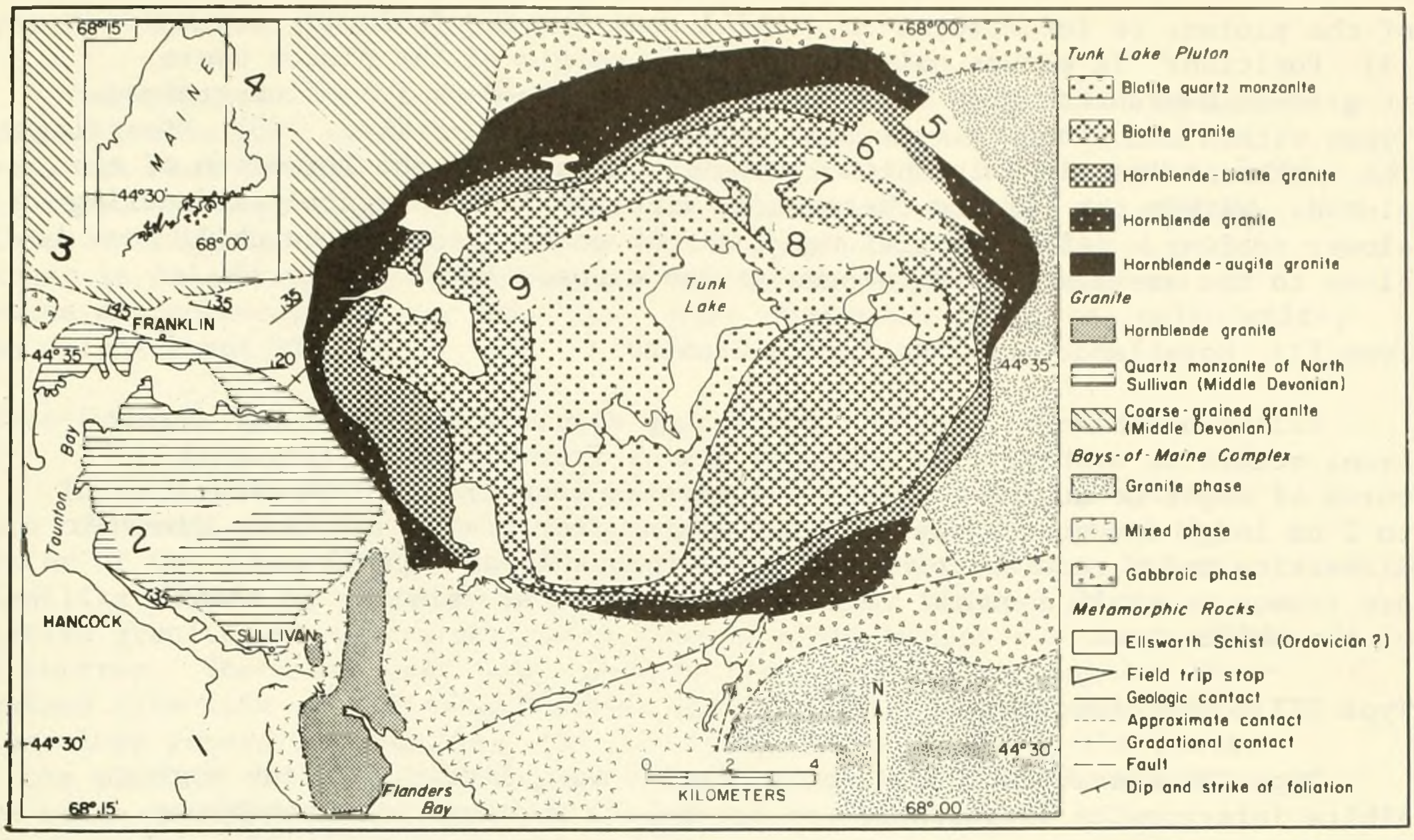

Figure 1. Geologic map of the Tunk Lake granite pluton (Karner, 1968).

Zone	Rock Type	Texture	Areal Extent	Quartz	Oligo-clase	Perthite	Albite in Perthite	Total Mafics + Acces-sories	Mag-netite	Aegir-ine Augite	Horn-blende	Biotite
I	Magnetite-aegirine augite granite	Medium-grained hypidiomorphic granular	....	30–40	<10	55–65	40–45	2–4	1	<1	<1	<1
II	Hornblende-aegirine augite granite	Medium-coarse-grained hypidiomorphic granular	8.7	20–25	< 5	60–70	45–50	6–10	1	1–2	3–5	<1
III	Hornblende granite	Medium-coarse-grained hypidiomorphic granular	10.2	25–30	< 5	55–65	40–50	4–7	1	<1	2–4	1
IV	Hornblende-biotite granite	Medium-coarse-grained hypidiomorphic granular	13.2	25–35	5–15	45–55	30–40	4–6	<1	......	1–2	1–3
V	Biotite granite	Medium-coarse-grained hypidiomorphic granular to porphyritic	40.4	30–35	15–25	40–50	25–35	3–5	<1	......	<1	2–4
VI	Biotite quartz monzonite	Medium-grained porphyritic to allotriomorphic granular	27.5	30–40	20–30	30–40	15–25	2–4	<1	......	......	2–4
Average				31	18	46	31	5	0.6	0.1	1.1	2.5

NOTE.—Areal extent expressed as percentage of total outcrop area. Mineral abundances expressed as volume percentages. Albite in perthite expressed as percentage of total perthite. Average weighted according to areal extent of zone. Modified from Karner (1968).

Table 1. Characteristics of rock types of the Tunk Lake granite pluton (Karner and Helgesen, 1970).

of the pluton, is interpreted as a chill zone for the following reasons: (1) Position: It occurs only at the outer margin of the pluton where it grades inward into zone II. (2) Texture: The rock is medium-grained. Types within the pluton are medium-coarse-and coarse-grained. (3) Mineralogy: The rock contains minerals which crystallized early in the formation of the pluton. Within the pluton these early minerals have recrystallized during slower cooling. (4) Composition: The bulk composition of the chill zone is close to the average for the pluton at the exposed level (Table 1).

Type II: Hornblende-Aegirine Augite Granite

Calcic hornblende, probably containing significant sodium and ferric iron, occurs as subhedral to euhedral grains from 2 to 3 mm long with cores of aegirine augite. Perthite occurs as subhedral grains from 1 to 2 cm long, and quartz, as anhedral grains from 1/4 to 1/2 cm in diameter. Riebeckite and a reddish-colored biotite (probably astrophyllite) are common in small amounts. Accessory minerals are similar to those of the chill zone.

Type III: Hornblende Granite

Type III resembles type II but contains very little aegirine augite. Albite intergrowths in perthite are irregular, forming patch perthites. A small amount of quartz is intergrown graphically-granophyrically with perthite. Accessory minerals include magnetite, zircon, apatite, allanite-epidote, and some fluorite. Small amounts of biotite and sphene are usually present.

Type IV: Hornblende-Biotite Granite

In type IV hornblende is present as subhedral grains which characteristically are partly rimmed and replaced along cleavage cracks by biotite. Some perthite grains have rims of oligoclase, and intergrown quartz is common. Most oligoclase occurs as subhedral grains from 1/4 to 1/2 cm long. Accessory minerals are similar to those of the hornblende granite.

Type V: Biotite Granite

In type V texture is variable. Fine- to medium-grained aggregates of perthite, oligoclase, quartz, and mafic minerals occur between coarser grains. Aggregates may be narrow zones between a few perthite grains, or they may be well developed and may completely isolate larger grains of quartz, feldspar, and mafic minerals. Accordingly, the texture may by hypidiomorphic-granular, seriate-porphyritic, sub-porphyritic, or porphyritic. Seriate textures are the most common. Patch perthite contains less exsolved albite than in outer zones and commonly has oligoclase rims (An_{21}) forming typical rapakivi texture. Oligoclase also occurs as discrete grains (An_{13}) up to one centimeter long. Quartz, graphically-granophyrically intergrown with perthite, is common. Much biotite is partly chloritized. Magnetite, sphene, and apatite are common accessories. Zircon and allanite-epidote are less abundant and less well developed than in rocks closer to the margins of the pluton. Fluorite is found locally.

Type VI: Biotite Quartz Monzonite

Textures of type VI are gradational with those of type V but medium-grained phases with texture similar to the groundmass of porphyritic types are most common. Mafic minerals include biotite, chloritized biotite, chlorite, and magnetite. Patch perthite contains very little intergrown albite. Oligoclase (An_{11}) has clear albite rims (An_3) and altered cores richer in calcium (An_{20}). Apatite and subhedral-anhedral zircon and sphene are common accessory minerals. Less common are fluorite, molybdenite, and allanite-epidote.

Finer-Grained Phases

In each of the six types, finer-grained variants are found within rock of normal texture. These phases are especially common toward the center of the pluton occurring as fine- to medium-grained irregular or sheetlike masses from several inches to many feet in width. In the biotite granite and quartz monzonite many of these masses may occur within an outcrop. There are gradations among aplites dikes, less regular fine-grained dike-like or sill-like bodies, and irregular fine-grained masses. Mineralogy generally resembles that of normal types closer to the center of the pluton. In the biotite granite and quartz monzonite these phases are often granophyric and miarolitic.

Form and Structures

In the pluton a resistant margin forms an outer rim of high hills, except to the south where shearing has weakened the granite. At the present level of erosion the pluton transects metamorphic and igneous rock masses of different age (Fig. 1). To the south contacts are unexposed or are in areas where the rocks are sheared and relations to the adjacent Bays-of-Maine complex are unclear. The dip of the contact surface of the pluton was not found in outcrops observed. In areas of contact with gabbro-diorite, a breccia occurs which contains subangular xenoliths up to at least several feet across. Outward from this zone the rocks and actual contact are covered. Characteristic topography in the contact zone is a steep outward slope at the outermost rock exposures. An abrupt change in magnetic properties at the edges of the pluton suggests steep contacts. Oriented fine-grained mafic xenoliths, slab-like and usually a few to several inches long, strike parallel to the contact of the granite and the country rock in the northwestern northeastern, and eastern margins of the pluton and dip inward at angles of about 30° to 40°, suggesting that the contacts of the zones may dip inward and that the outer contact may also dip inward (Karner and Connors, 1971). Rocks of the pluton are generally massive. Parallelism of tabular perthite grains causes a faint layered appearance in a few specimens from the contact phase. Perthite grain alignment around some inclusions suggests that the parallelism of feldspar in these rocks is a primary flow structure. Oriented xenoliths may also indicate magmatic flow.

Major joint trends for the pluton are E-W, WNW, NE, and ENE. Most joints are vertical or steep. Subhorizontal sheeting is common. Aplite dikes occur throughout the pluton but are most common in the central part. Major trends are NW and NNE. Dikes, often a few inches wide and steeply dipping, consist of abundant quartz and sodium-poor perthite, subordinate plagioclase, and small amounts of biotite, chlorite, and opaque minerals. Often the dikes have central openings almost completely filled by inward-projecting feldspar and quartz crystals up to several centimeters across. Quartz veins, an inch or so wide, and zones of quartz veinlets sometimes occur in the central zones. Major trends are E-W, WNW, and ENE. Mafic dikes are rare. One, 2-4 m wide is exposed at location U 6.5, V 22.1 (Fig. 2). It contains abundant xenoliths of granite and with several adjacent narrower dikes trends east-west and is approximately vertical. Sulfide mineralization is present on faces of a WNW joint set at the location mentioned above. Molybdenite occurs in the central zones in altered granite and in quartz and aplitic veins particularly on Catherine Mountain (Trefethen and Miller, 1947, Young, 1963).

Compositional Variation

Compositional variation in the pluton has been studied primarily by modal analysis of thin sections. Some chemical work has been done and extensive major and trace element studies of both bulk composition and mineral phases have been undertaken. Bedrock exposures are usually found on the sides and tops of hills 15 m or more in height. Exposures present in low areas indicate that they are often underlain by rock which is more strongly fractured or more mafic than that of the higher well-exposed parts of the pluton. The low areas are generally those marked unsampled on Figure 2. Specimens from 140 field stations (Fig. 2) were chosen for study of compositional variation. A series of closely spaced specimen locations was chosen along the E-W Tunk Lake section. The mineralogical composition of the pluton varies systematically from the margins inward (Karner, 1968; Table 1; Fig. 2). In Figure 2 values for the thin marginal zone I are not shown. Modal variation may be summarized as follows:

(1) The quartz content decreases from an average of 34 percent in zone I to 22 percent in zone II, and then increases to 35 percent in the core, zone VI.

(2) The perthite content decreases from 57 and 65 percent in zones I and II to 35 percent in the core zone VI, while its albite content decreases from 45 percent to 21 percent. Oligoclase varies antipathetically with perthite and increases from about 5 percent in zones I and II to 27 percent in zone VI.

(3) The dominant mafic mineral varies according to the series magnetite-aegirine augite-hornblende-biotite. Total mafics and accessories average 3 percent in zone I, increase to 8 percent in zone II, and decrease to 4 percent in the core, zone VI.

(4) Modal data vary regularly from the margin of the pluton inward. Contours generally parallel the outer contact of the pluton and the zone boundaries as recognized in the field. Total mafics and accessories show the greatest deviation from regular variation.

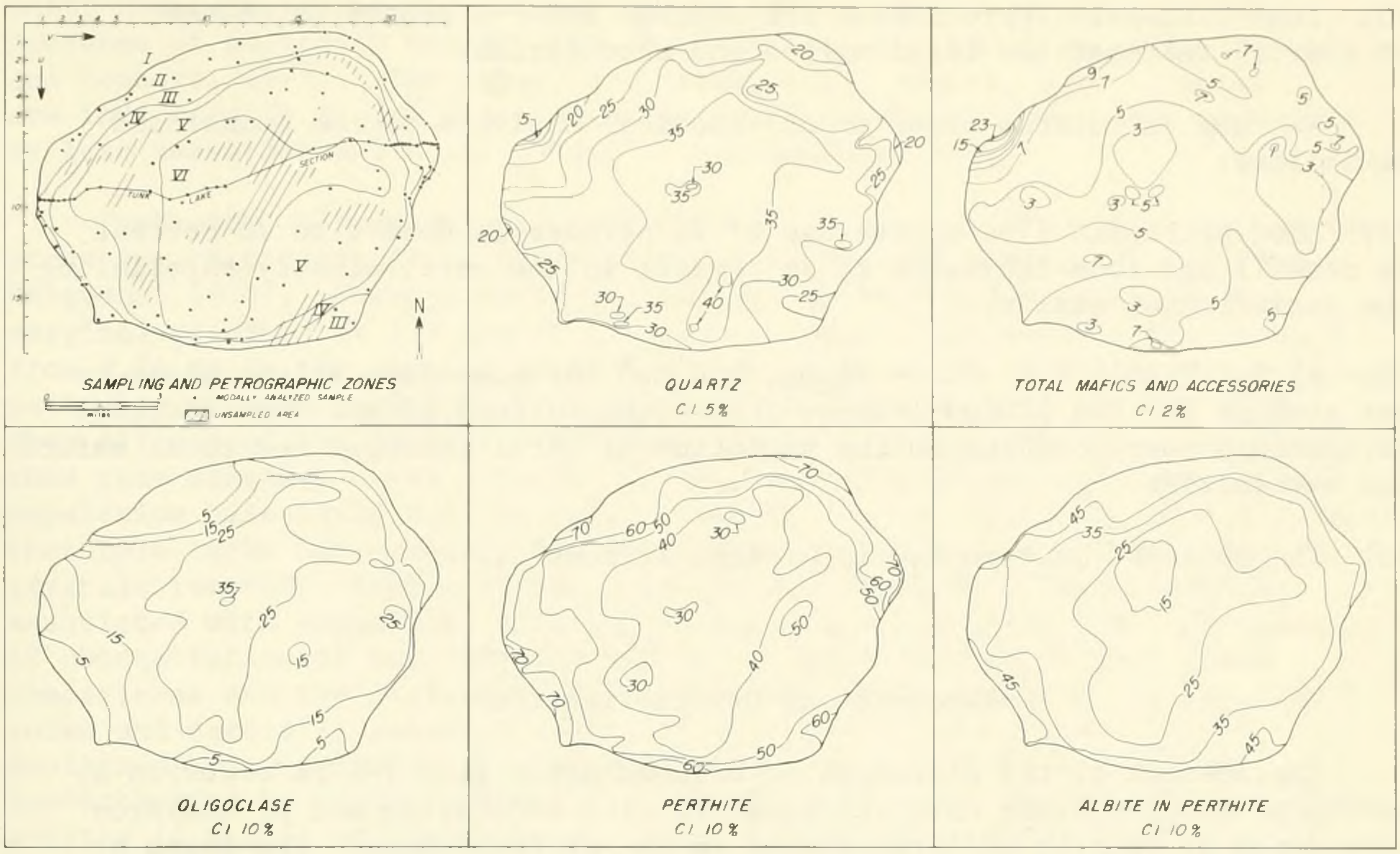

Figure 2. Modal variation (vol. %) in the Tunk Lake pluton (Karner, 1968).

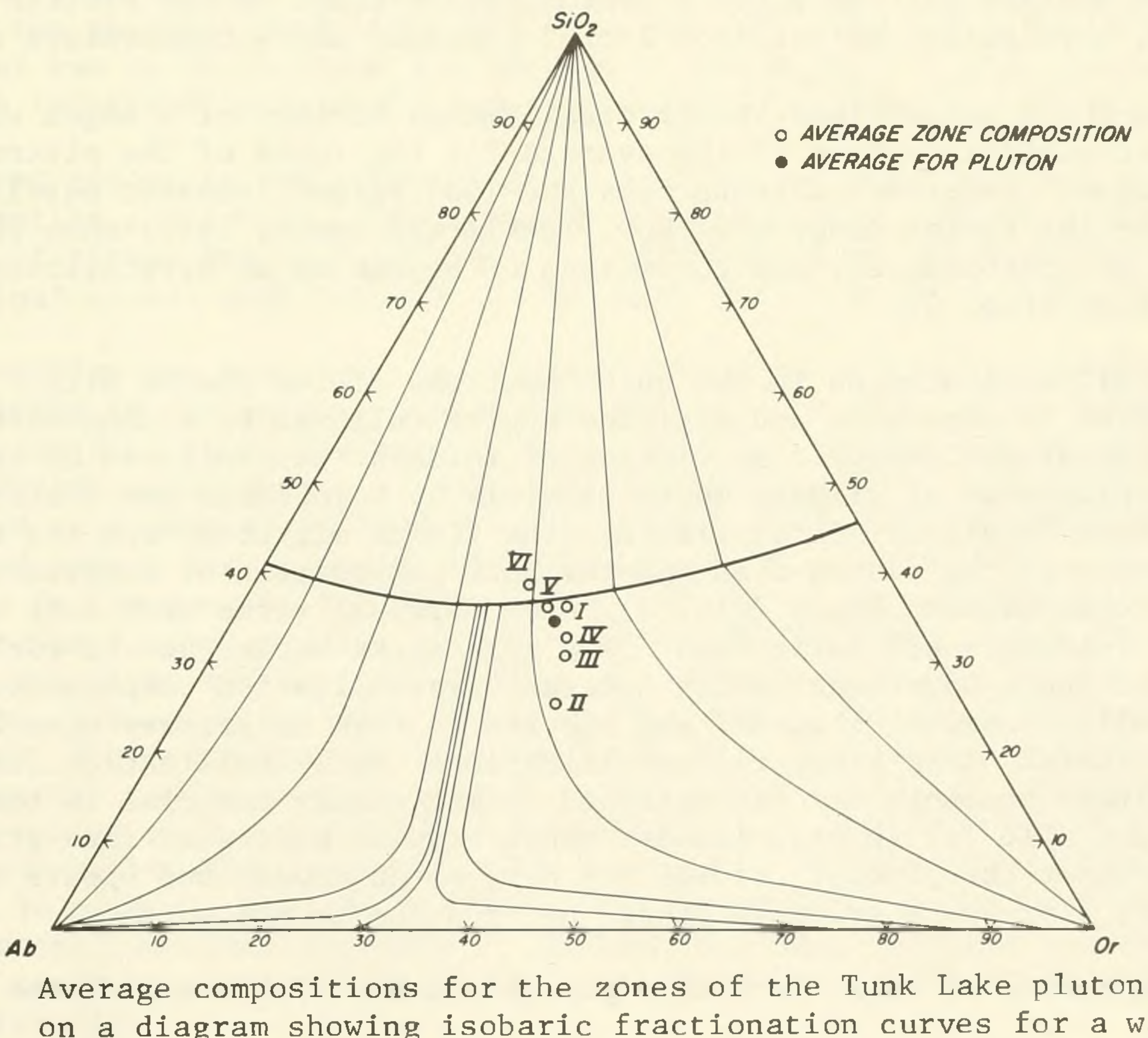

Figure 3. Average compositions for the zones of the Tunk Lake pluton plotted on a diagram showing isobaric fractionation curves for a water-vapor pressure of 1000 kg/cm^2 in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O (Tuttle and Bowen, 1958).

(5) Zone I closely approximates the average for the pluton in content of quartz, feldspar and total mafics and accessories.

Wet and calculated (from modes) chemical analyses may be summarized as follows:

(1) SiO_2 decreases from an average of 76 percent in zone I to 70 percent in zone II and then increases to 76 percent in the core, closely paralleling the variation of quartz.

(2) Al_2O_3, $Na_2O + K_2O$, $FeO + Fe_2O_3$, and CaO increase from values close to the average for the pluton in zone I to highs in zone II and then decrease to the core corresponding to the variation of total feldspar and total mafics and accessories.

(3) The ratio of Na_2O to K_2O is highest in zone II.

Emplacement and Crystallization

Emplacement of the pluton at an assumed depth from 2-5 km occurred by piecemeal stoping along marginal zones of ring fracturing and by cauldron subsidence or stoping of large blocks in the central zones. The magma at the time of intrusion is assumed to have had a composition, indicated by a calculated average for the pluton, approximately equal to the biotite granite of zone V, a volatile content from 2 or 3 percent, and a temperature of 800° C.

Using these assumptions the crystallization history of a magma with a composition similar to that of the average for the rocks of the pluton can be summarized. Experimental data from the 1000 kg/cm^2 isobaric equilibrium diagram for the system $Ab\text{-}Or\text{-}SiO_2\text{-}H_2O$ (Tuttle and Bowen, 1958) show phase relations at approximately the conditions of beginning of crystallization of the pluton (Fig. 3).

Crystallization began in the outer portions of the pluton with precipitation of magnetite and aegirine augite followed by sodium-rich alkali feldspar and quartz. Exsolution of feldspar was followed by the partial replacement of primary mafic minerals by hornblende and biotite. During crystallization, silica-rich aqueous fluids migrated from the margins to the center of the pluton changing the bulk composition of successive internal zones of the pluton (Fig. 3). The marginal rocks were left quartz-poor, and feldspar- and mafic-rich. The core rocks became quartz-rich. In the central zones additional water lowered crystallization temperatures allowing oligoclase, hornblende, and biotite to form as primary minerals and also facilitated late-stage recrystallization. Recrystallization fluxed by hydrous fluids accounts for fine-grained intergranular material in the central granites and also for sheets, lenses, and irregular bodies of fine-grained rock throughout the pluton. Fluids may have moved inward and upward in response to a pressure gradient caused by eruption at the surface.

Assimilation of mafic rock is a possible cause of the enrichment of mafic minerals in the outer zones of the pluton and is supported by the presence of partially assimilated inclusions in the marginal rocks (Karner and Connors, 1971). The large, low areas of the pluton, some of which are indicated in Figure 2 as unsampled areas, may represent zones underlain by less resistant mafic inclusions or contaminated rocks.

Systematic zircon and zirconium variation gives further information on processes that operated in the pluton during crystallization (Karner and Helgeson, 1970). Average zirconium content decreases from 660 ppm in marginal granites to 170 ppm in the core. Zircon decreases in mean length from 0.24 mm in the margins to 0.13 mm in the core. Core zircons tend to be partially metamict and less elongate and have more complex crystal form than zircons of the margins. Frequency distributions of zircon characteristics show that marginal rocks contain zircon populations similar to the average population calculated for the pluton but with additional large crystals, and that core rocks have populations similar to the average but with large crystals removed. Broken zircon crystals and clusters of many crystals associated with magnetite, allanite-epidote, and sphene support the concept of concentration of early-formed zircon by mechanical movement. These comparisons and the enrichment of relatively fresh zircon in the marginal rocks and partially metamict zircon in the core of the pluton can be explained by a mechanism involving gravity settling. The concept of concentration by gravity settling is appealing because of the high specific gravity (4.6-4.7) of fresh zircon. Shaw's (1965) data show that large zircons 0.03-0.05 cm in length would settle at rates of 0.02 - 0.06 m/year. This rate seems inadequate since the granite magma would have to remain fluid in the margins, even the chill zone, for an increase of zirconium content of two or three times the average. Two additional factors may have been important in accelerating zircon concentration.

Zircon occurs in the outer rocks as clusters of many crystals associated with magnetite and sphene, both probably also of early crystallization. Clusters of zircon and magnetite 0.1-0.3 cm in diameter, as are common in the marginal zones, would have settling rates on the order of 0.3 m/year.

Convection may also have accelerated zircon concentration in the margins and depletion in the core by upward movement in the center of the magma chamber and downward flow along the walls. Shaw (1965) discusses such flow regimes in cylindrical magma chambers. The pluton's oriented mafic xenoliths which dip inward at angles of 30^{o}-40^{o} in the marginal rocks may parallel flow lines. Inward and upward flow has already been suggested to explain the enrichment of quartz in the core of the body and its depletion in the margins. Figure 4 schematically illustrates the magma chamber along the Tunk Lake section, assuming the above two aspects of flow as indicated by solid arrows. Zone boundaries, zirconium content, and areas of zircon enrichment and depletion are shown. The pattern is interpreted as a section through the lower part of two convection cells, as indicated by dashed arrows. Zircon accumulated where downward-moving magma was slowed and deflected inward. Shaw (1965) estimates average convective flow velocities for a somewhat smaller magma chamber to be about 10 m/year. Average velocities on the order of meters per year would have augmented downward movement of zircons or zircon clusters in the marginal areas and yet could have allowed zircons to settle where currents moved laterally.

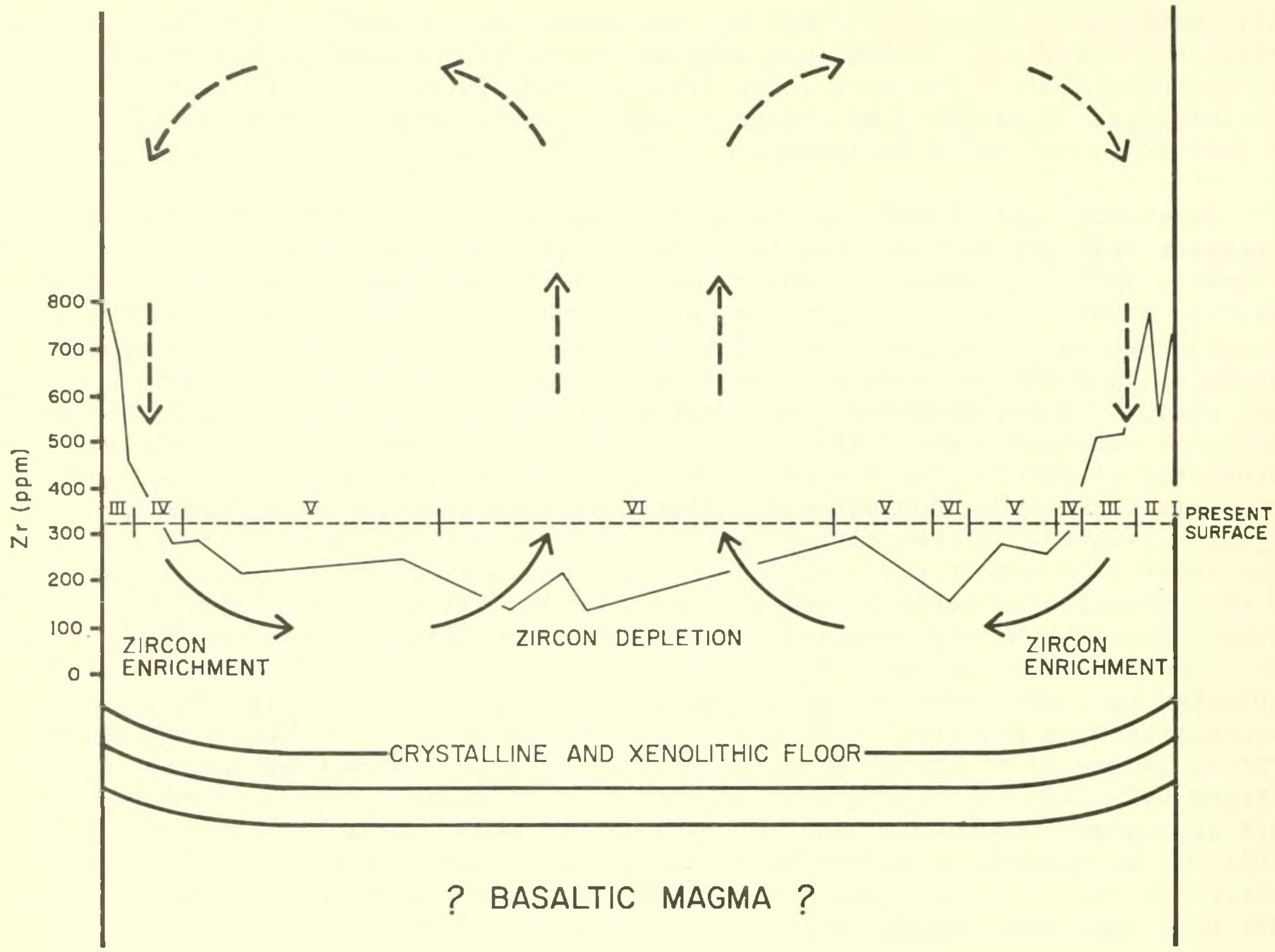

Figure 4. Diagrammatic illustration of convection cells in the Tunk Lake pluton postulated on the basis of zircon data (Karner and Helgesen, 1970). Zone boundaries and zirconium values from the Tunk Lake section (Fig. 2).

There are several possibilities for the pluton's shape and composition below the presently exposed level. If the convection cells of Figure 4 are minor, such as the secondary cells discussed by Shaw (1965), they may be underlain by other minor or major convection cells. If the flow patterns are the major convection cells of the Tunk Lake magma chamber, Shaw's (1965) treatment suggests the presence of a large underlying magma reservoir or a floor. The presence of a floor is assumed here because zircons would not be likely to accumulate at the base of a convection cell underlain either by a large magma reservoir or by other convection cells.

Melting-Anomaly Control

The pluton is within the Maine Coastal belt (Chapman, 1968b) and is related to several other circum-Atlantic groups of intrusions including the White Mountain plutonic-volcanic series of New Hampshire. Karner (1973, and in preparation) has suggested a New England melting-anomaly origin for the Maine Coastal and White Mountain bodies because of similar structural relationships and alkaline petrologic characteristics.

The Maine Coastal and White Mountain bodies (Fig. 5) are well known as two geographically separated groups of igneous complexes formed in the northern portion of the Appalachian tectonic belt. Twenty complexes in the Maine coastal region form a belt about 50 km wide which extends about 130 km northeast from Penobscot Bay and are assigned Devonian ages. About fifty separate centers of intrusive or extrusive igneous activity, composing about fifteen major central complexes and numerous minor and satellitic bodies, have been recognized in the Mesozoic White Mountain belt which is about 75 km wide and extends about 250 km from southern Maine and New Hampshire north-northwest to Vermont.

Similarities in structural relationships of both belts include: (1) crescentic, circular, and elliptical outcrop patterns which are generally interpreted as indicating ring dikes and stock-like intrusive forms; (2) occurrence of volcanic rocks and hypersolvus petrographic types suggesting shallow levels of intrusion and accompanying volcanic activity; (3) post-tectonic age in folded rocks of the New England Appalachians; and (4) reticulate patterns as noted by Chapman (1963, 1968a, 1968b) with plutons located at the intersections of inferred fracture sets. Chapman's (1968a) reticulate patterns are modified and related to major structural elements (Karner, in preparation). The patterns are NE and ENE for the Maine Coastal bodies. They are E-W and NNW for the White Mountain bodies in central New Hampshire, NE and ENE in southern Maine and New Hampshire, and E-W and NNE in northern New Hampshire (Fig. 5). In the Maine Coastal area the acute angle of the reticulate pattern of plutons is bisected by the trend of the proposed Maine Coastal Anticlinorium. The White Mountain belt extends NNW across the Rockingham Anticlinorium, Merrimack Synclinorium and the Bronson Hill-Boundary Mountain Anticlinorium. Most of the major plutons are in the Merrimack Synclinorium where the obtuse angle of the reticulate pattern is cut by the structural trend.

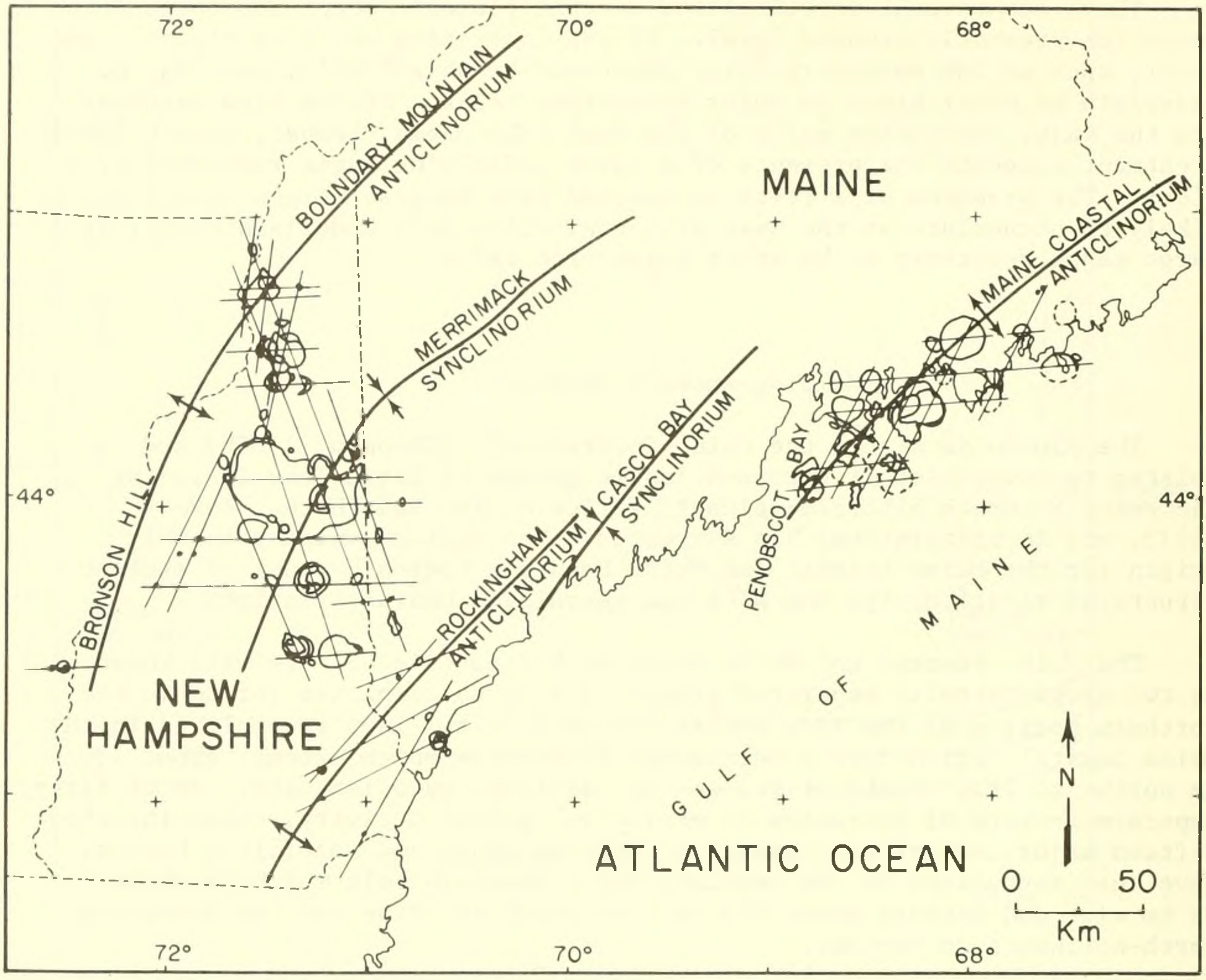

Figure 5. Igneous bodies of Maine Coastal belt in southeastern Maine and White Mountain plutonic-volcanic series in New Hampshire. Distribution of igneous bodies and rectilinear patterns modified from Chapman (1968a). Diagram from Karner (in preparation).

The reticulate patterns are believed to follow conjugate shear sets (Price, 1966) for anticlinal and synclinal structures.

In both belts a mildly alkaline rock series with the following major characteristics is present: (1) Early mafic phases including basaltic and gabbroic-dioritic rocks occur but are minor in abundance at exposed levels. (2) Initial felsic phases are quartz rich, occuring as Moat volcanics in the White Mountain area and as a distinctive chill zone in the Tunk Lake pluton. (3) Succeeding, felsic plutonic phases are predominantly intrusive and follow the sequence; undersaturated to saturated pyroxene-amphibole syenite, aegirine augite-hastingsite-riebeckite quartz syenite and quartz-poor granite ---- hornblende granite ---- hornblende-biotite granite ---- quartz-rich biotite granite and quartz monzonite. (4) The rock series are dominantly granitic with later subsolvus, mildly alkaline to calc-alkaline biotite granites and quartz monzonites by far the most common rock types. (5) Mineralogically, syenites and hypersolvus, quartz-poor granitic phases are most alkaline as demonstrated primarily by Na-rich minerals including Na-rich alkali feldspar, aegirine augite, hastingsite, riebeckite and astrophyllite. Distinctive minor minerals and accessories are fayalite, zircon, sphene, fluorite and allanite-epidote. (6) Chemically, the early felsic plutonic phases are relatively high in Na and K and low in Al and Ca compared to later calc-alkaline members and also contain trace element abundances characteristic of alkaline felsic rocks, such as high Zr.

In the Tunk Lake body the variations occur in a single zoned intrusion while in the White Mountain belt the rock types occur in composite bodies. Variation trends are parallel as shown on Figure 6, and with the similar petrographic characteristics discussed above, indicate a common genetic history. The Tunk Lake body is interpreted as a differentiated felsic cap produced from a convecting, mildly alkaline, granitic magma located above a mafic magma rising in a circular conduit. The White Mountain bodies and other Maine Coastal bodies are interpreted in a similar way by Chapman (1968b).

Morgan (1971, 1972) and many others (Karner, in preparation) have suggested a mantle-plume origin for the White Mountain series associating it with the New England Seamounts and present sites of Atlantic volcanism.

Karner (1973 and in preparation) makes the following major observations: (1) The Maine Coastal and White Mountain igneous bodies are structurally and petrographically similar, post-tectonic, mildly alkaline, plutonic-volcanic complexes in the northern portion of the Appalachian tectonic belt deformed during the Acadian Orogeny. (2) They have been emplaced at different times into markedly different geologic terranes as mafic bodies with granite caps. The Devonian Maine Coastal bodies are in a zone of gravity and magnetic highs in the proposed Maine Coastal Anticlinorium and the Mesozoic White Mountain bodies are largely in a zone of gravity and magnetic lows in the Merrimack Synclinorium. (3) In both areas, the bodies form reticulate patterns equivalent to conjugate shear directions of the enclosing major structures. (4) Both series have mildly alkaline petrographic characteristics and similar differentiation trends. (5) A mantle-plume (melting-anomaly) origin has been suggested by many workers for the White Mountain series relating the alkaline igneous activity to early stages in the separation of North America and Africa.

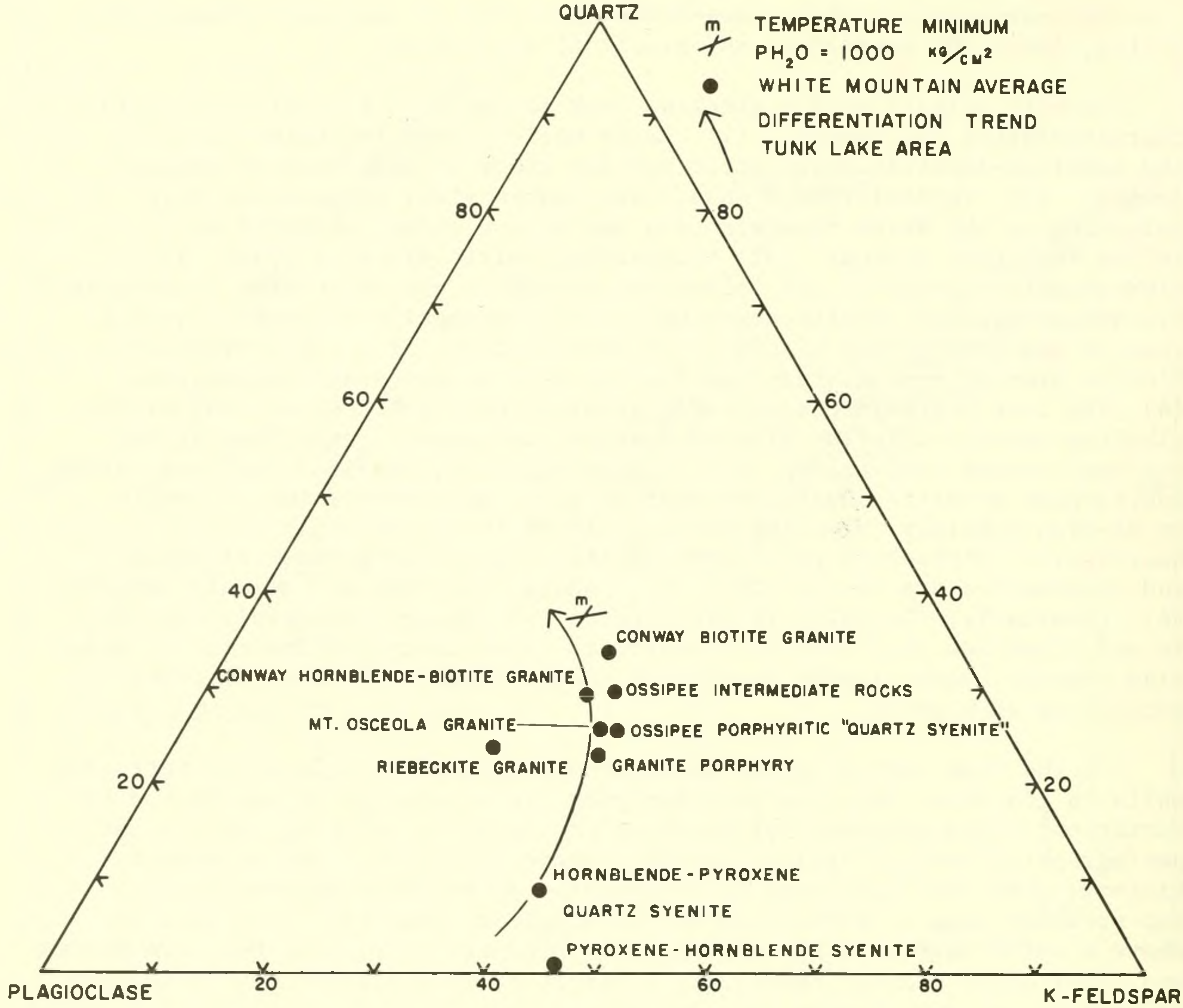

Figure 6. Variation of modal quartz, plagioclase and K-feldspar for the White Mountains plutonic volcanic series (Karner, 1968; Karner, and Bertram, 1972) and the differentiation trend of the Tunk Lake pluton (Karner, 1968) of the Maine Coastal series. The ternary minimum at 1000 kg/cm^2 is from work by Tuttle and Bowen (1958). Diagram from Karner (in preparation).

Karner (1973, in preparation) reaches the following tentative conclusions: (1) The Maine Coastal and White Mountain series have similar melting-anomaly origins. (2) Since the two series are emplaced into markedly different surface geologic terranes there is a deeper control of their formation, possibly the lower crust or upper mantle. (3) Since the patterns of the igneous bodies follow conjugate shear intersections and since they are inferred to have risen vertically from depth, the conjugate shears are characteristic of the rocks at depth. The shear intersections are present in a folded or undulating deep lithosphere as zones of weakness formed during the Devonian Acadian Orogeny and opened as magma conduits during Late Devonian-Carboniferous rifting in the Maine Coastal area and Mesozoic rifting in the White Mountain region. (4) A mantle source of alkali olivine basalt magma combined with partial melting of more felsic rocks is proposed to account for the petrography of the two series. (5) A New England melting anomaly related to deep folds or undulations or possibly other physical characteristics of the New England portion of the American lithospheric plate is proposed as an alternative to a melting anomaly related to present sites of Atlantic volcanism (thermal plumes).

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Itinerary

The field trip is designed so that we can study (1) the contacts with a variety of older rocks, (2) the unique chill zone, and (3) the gradation from hypersolvus, alkaline, pyroxene-granite to subsolvus, biotite, quartz monzonite in the concentrically zoned, Devonian, Tunk Lake pluton. Various features of the pluton including evidence for convective flow, typical rapakivi texture, and molybdenum mineralization will be examined. Please note that the field trip requires an 0.7 mi. hike from the north side of Catherine Mountain at elevation 470 ft. to the top at elevation 942 ft.

Mileage

0.0 Assembly Point. Intersection of U.S. 1 and Maine 185 about one mile east of Sullivan, Maine.

Stop 1. Contact Zone of Southern Mixed Phase and Hornblende Granite. In this area, southwest of the Tunk Lake pluton, a mixed phase of diorite-gabbro cut by various types of granitic rocks is exposed as well as an elongate body of hornblende granite which may be related to the Tunk Lake body and is possibly a faulted segment of the southern margin of the pluton (Fig. 1). Note the following:

(1) The body of hornblende (aegirine augite?) granite east of the intersection. At small exposures 0.2 mi. east note the NNW orientation of compositional variants, elongate minerals, mafic xenoliths and shear? surfaces. Flow during emplacement and/or later tectonic deformation may have been involved in the formation of these features.

(2) The mixed phase exposed northwest of the intersection for about 0.3 mi. In the mixed phase, lighter rock types always cut darker, and darker types are always included in the lighter. Here, diorite-gabbro is cut by veins of hornblende granite as well as by a whitish, biotite- and plagioclase-bearing granitic phase. A hornblende granite dike? contains mafic xenoliths. Greenish-yellowish hornblende-aegirine augite granites and

syenites? (particularly to the northwest) are the most alkaline in appearance. Such rocks usually contain sodic-microperthite, aegirine augite, hastingsite, riebeckite and fayalite.

Return northwest on U.S. 1 toward Sullivan.

0.8 Approximate position of southeast contact of the North Sullivan pluton (Fig. 1). The uniform, medium-grained, biotite quartz monzonite of this pluton has been quarried extensively in the Sullivan-Franklin area. The contact zone is well-exposed on the west side of York Hill just to the southwest of the highway.

1.0 Turn north (right) on Maine 200. For the next 5.1 miles the road crosses the eastern part of the North Sullivan pluton. There are several small outcrops along the road.

2.9 Stop 2. <u>North Sullivan Biotite Quartz Monzonite</u>. Just east of the road a small outcrop of the typical rock is exposed. About 1.6 mi. northeast this rock is in contact with the marginal facies of the Tunk Lake pluton and is slightly altered suggesting that it is older. Note the following:
(1) Medium-grained biotite quartz monzonite of the North Sullivan pluton.
(2) Scattered small dark xenoliths.
(3) A narrow mafic dike.

Continue north on 200.

4.6 East Franklin.

6.1 Intersection of side road to northeast and approximate position of the north contact of the North Sullivan pluton with the Ellsworth Schist (Fig. 1).

6.9 Franklin. Turn northeast (right) on Maine 182.

7.8 Bayview Cemetery. Turn northwest (left) on road to Georges Pond.

8.1 Stop 3. <u>Contact Zone of Ellsworth Schist and Coarse-grained Biotite Granite</u>. A series of exposures of Ellsworth Schist about 0.1 mi. south of the road extends parallel to the road from the north side of the knoll behind the cemetery for about 0.3 mi. northwest to the covered contact of the coarse-grained, biotite granite (Fig. 1). The Ellsworth Schist is in a wedge-shaped area between at least three intrusions here (Fig. 1) and is strongly deformed. Note the increasing modification of the schist northwestward as shown by:
(1) Variation of foliation from well developed planar to contorted to weaker irregular foliation or almost massive structure.
(2) Progressive coarsening of texture.
(3) Increase of granitic vein material.

(4) Modification of amphibolite layers (probably originally basaltic sills) to contorted layers to aligned amphibolite boudins to unoriented amphibolite inclusions.

Return southwest toward Maine 182.

8.4 Intersection Maine 182. Turn northeast (left) on 182.

9.0 Approximate northern contact of Ellsworth Schist with the coarse-grained, biotite granite. For the next 4.3 miles the road crosses the southern part of this granite.

10.4 Stop 4. Coarse-grained Biotite Granite with Rapakivi Texture. Road cut on north side of highway just southwest of east end of old highway segment and opposite road to Duck Pond. The outcrop area of this rock type is cut by the younger Tunk Lake pluton about 0.8 mi. to the southeast (Fig. 1). Note the following:
(1) Typical coarse-grained biotite granite with perthite megacrysts up to 10 cm long.
(2) Occasional mantling of the perthite with plagioclase producing typical rapakivi texture.
(3) Mantling of perthite megacrysts in xenoliths.
(4) Scattered (and oriented?) mafic-rich areas in the granite.

Continue northeast on 182.

13.3 Approximate contact area of coarse-grained biotite granite to northwest, diorite gabbro to northeast and the Tunk Lake pluton to south (Fig. 1). For the next 9.2 mi. the road crosses the northern part of the pluton from margin to core and back out to the first stop at the eastern margin of the pluton. For succeeding stops, the field trip route will return on Maine 182 and end in the core of the pluton (Fig. 1).

13.6 Hornblende-aegirine augite of marginal zone II of the pluton is exposed on hills north and south of the road.

14.2 Approximate contact of zone II and zone III, hornblende granite.

15.0 Hornblende granite of zone III exposed along road at east end of Fox Pond.

15.3 Approximate contact of zone III and zone IV hornblende-biotite granite.

Catherine Mountain in the core of the pluton is southeast.

15.6 Approximate contact of zone IV and zone V biotite granite. The road is crossing the north flank of Catherine Mountain.

17.8 Tunk Lake. The road continues east across the core and back through the zones to the east margin of pluton.

22.1 Stop 5. Eastern Margin and Contact Zone of Tunk Lake Pluton. East end of road cut on Burke Hill at old highway cutoff access road. The biotite granite east of the pluton and the chill zone I of aegirine augite-magnetite granite gradational with zone II of hornblende-aegirine augite granite are exposed at this location (Fig. 1). Follow the blueberry-field access trail from about the middle of the old highway section eastward (parallel to the highway) about 0.3 mi. to near the eastern base of the N-S ridge marking the contact zone and resistant margin of the pluton. North and south of this location the contact zone is well exposed with a variety of mafic to felsic rocks present. Here and as you follow westward to the road cut note the following:

(1) The whitish tan medium-grained, hypidiomorphic granular, hypersolvus magnetite-aegirine augite granite of the chill zone I. The rock is strongly magnetic and this zone may account for the poor topographic rendering of this area on the Cherryfield 15' quadrangle map. Close to the contact some phases of the chill zone are unusual in that they are accessory mineral granites with no common ferromagnesian mineral, only about 1-2% magnetite, zircon, sphene and allanite-epidote in addition to feldspar and quartz.

(2) The older, medium-grained, biotite granite which is tan-lavender close to the contact and resembles the rock of the chill zone but, is clearly different in color and texture to the east farther from the contact.

(3) The transition of rock type I of the chill zone to type II, hornblende-aegirine augite granite. The grain size increases from medium-grained to coarse-grained. The color changes from whitish tan to the typical yellowish tan and green of alkaline granites. The color index increases from 1-3% to 6-8%, perthite increases from 50-55% to 70-75% and quartz decreases from 30-40% to 20-25%. The major changes occur in the first 30-50 m inward.

(4) The abundant, oriented, slab-like, mafic xenoliths which trend N-S to NW parallel to the contact and dip inward toward the center of the pluton at angles of 20^{o}-45^{o}. Detailed study suggests that xenolith abundance and orientation (strike) varies cyclically in zones parallel to the margin. The xenoliths are typically recrystallized mafic rocks consisting of about one-third aegirine augite and two-thirds albite-rich microperthite.

(5) Mineralization of N 80^{o} W and other joint surfaces at road cut.

(6) Mafic dike exposed on north side of highway of road cut. The dike is several meters across, oriented E-W and almost vertical. It shows chilling at its contact with the granite and contains many xenoliths of granite in various states of partial assimilation. This and one or two other mafic dikes were the only ones found in the pluton.

Return west on Maine 182.

22.3 Approximate contact zone II and zone III, hornblende granite.

22.6 Stop 6. Hornblende Granite, Zone III. Outcrops of zone III north and northwest of two houses on the north side of 182 (Fig. 1). Note the following:
(1) Typical medium-coarse-grained hornblende granite of zone III. The rock has aegirine-augite only as tiny cores of hornblende crystals and slightly more quartz than type II. It is gradational with type II to the east.
(2) Abundant finer grained phase as dikes and irregular masses in the granite.

Continue west on Maine 182.

22.8 Approximate contact zone III and zone IV, hornblende biotite granite.

22.9 Stop 7. Hornblende-Biotite Granite, Zone IV. Outcrops north and east of cleared area north of the road (Fig. 1). Note the following:
(1) Typical medium-coarse grained hornblende-biotite granite of zone IV. It is gradational with type III to the east.
(2) Scattered buff and pink perthite grains mantled with white oligoclase.

Continue west on Maine 182.

23.0 Approximate contact zone IV and zone V, biotite granite.

23.1 Stop 8. Biotite Granite of Zone V with Rapakivi Texture. Road-cut on south side of road just west of Tunk cabins and just east of Washington-Hancock county boundary (Fig. 1). Note the following:
(1) Typical medium-coarse-grained, hornblende-biotite granite of zone V. The rock contains 30-35% quartz and 10-15% oligoclase. It is gradational with type IV to the east.
(2) Abundant pink to buff perthite grains mantled with white oligoclase to give typical rapakivi texture. A discontinuous rim of graphic quartz is present between rims and cores. The oligoclase is in optical continuity with exsolved albite in the perthite. Mantled feldspar typically occurs in this and adjacent zones and is believed to develop as the result of simultaneous hornblende to biotite reaction and feldspar exsolution.
(3) Development of fine-to medium- grained intergranular material (by recrystallization) producing hypidiomorphic granular to sub-porphyritic to seriate porphyritic to porphyritic textures in this zone.
(4) Several aplite dikes.
(5) Scattered, thoroughly recrystallized, medium-grained xenoliths 1-2 cm in diameter recognized as more or less equidimensional concentrations of ferromagnesian minerals. They are believed to be extensively recrystallized as a result of having been circulated several times through the magma chamber by convection currents in contrast to the less reacted xenoliths of the marginal rocks.

Continue west on Maine 182.

23.9 Approximate contact zone V and zone VI, biotite quartz monzonite. Type V is exposed on top of the small hill to the north and type VI on the hill's west side just ahead of us north of the road near the north end of Long Pond. Type VI is well-exposed on Round Mountain to the south.

26.4 Tunk Lake.

27.4 Stop 9. Biotite Quartz Monzonite Zone VI and Molybdenite Mineralization on Catherine Mountain. Starting at the northwest end of the cleared area follow an old trail 0.3 mi. northwest then 0.2 mi. southwest to the east side of Catherine Mountain and then walk 0.2 mi. west to the top (Fig. 1). Note the following:
(1) The typical, medium-grained to porphyritic biotite quartz monzonite of zone VI. It contains about one-third quartz K-feldspar and oligoclase with 3% biotite and magnetite. It is gradational compositionally and texturally with rocks of zone V.
(2) Abundant finer grained phases and aplite.
(3) The many molybdenite prospects around the top with mineralization in miarolitic cavities and in veins and on joint surfaces.

End.